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NEW YORK'S EXTENSION OF ITS SOURCES TO THE DELAWARE

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NEW YORK'S EXTENSION OF ITS SOURCES TO THE DELAWARE

Karl R. Kennison,[1] M. ASCE

New Yorkers are justifiably proud of their water supply. Being in a class by itself as to size it is difficult to make comparisons, but its quality is unexcelled among large municipal supplies. However, there is at least one disadvantage of size in that the City's growing needs have, for many years past, created what practically amounts to a continuous water supply emergency. For example, it takes about 15 years to authorize, design and construct a new major increment of the water supply development. To most cities an additional source yielding as much as 200 mgd would give a considerable measure of relief. However, New York's needs grow so rapidly that unless any increment to its supply should exceed that figure, it would stand a good chance of being entirely consumed as soon as it could be made available. When I recently transferred my activities from the water supply of the Boston Metropolitan District I had to multiply all my thinking by about six.

From the beginning when the City's Board of Water Supply was created in 1905, it has recognized that the problem of finding more supplies would be a continuous one, and hence the Board was set up as a permanent independent agency. It is engaged only in the planning, design and construction of the works, that is, making the capital expenditures, and when the works are completed they are turned over for operation and maintenance to a municipal department, the Department of Water Supply, Gas and Electricity.

Figure 1 shows the growth in the City's demand for water, and the nip-and-tuck race between demand and supply. Before New York obtained its first water from the Delaware Basin it could count on a safe yield from its sources of little more than 1100 mgd although those sources had actually been called upon for over 1200 mgd in 1948 and 1949, a situation which led to drastic conservation measures in which the public cooperated fully. Upon completion of the Delaware River works authorized to date, it is estimated that the safe yield of all sources will be 1460 million gallons daily. Ground waters from wells in Long Island can supplement the supply at present to a very limited and decreasing extent but cannot be counted on in the future and hence are not included in the future safe yield. The consumption of the City, including a small supply required by outside communities, averaged in 1953 about 1139 mgd; and to be safe, the addition of an average annual increase of not less than 20 mgd has to be anticipated. A daily high of over 1600 mgd was consumed in the summer months of last year.

The Board of Water Supply, from its inception, recognized the necessity for a thorough comprehensive survey looking far into the future and weighed the possibility of obtaining a non-gravity supply from ample near-by sources requiring filtration against a program of going continually further afield for gravity supplies from relatively clean upland sources. The Board, with the backing of the City's administrative and fiscal agencies, and of the State Water Power and Control Commission, has chosen the latter course, developing the upland gravity supplies.

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1. Chief Engineer, New York City Board of Water Supply.

Figure 2 shows the City's sources, and a profile of the Delaware Aqueduct which was designed to deliver the supplies diverted and to be diverted from New York's Delaware River tributaries.

Following is a brief description of these various New York sources:

The Croton Supply, which has a present safe yield of 330 mgd was already in use when the Board of Water Supply was organized in 1905. The principal structures in the two Croton Aqueducts, the old and the new, and the new Croton Dam mostly of stone masonry with gravity section, 174 feet high, and 297 feet above its foundation. Its spillway is at elevation 200, permanent flashboards 202. In this Croton system 12 reservoirs and 6 controlled lakes impound with flashboards, 103 billion gallons, from 375 sq. mi. drainage area of the Croton River in Westchester and Putnam Counties.

The Catskill Supply has a safe yield of 555 mgd, 340 from the Ashokan Reservoir, first made available in 1915, and 215 from the extension to Schoharie Reservoir.

The Ashokan Dam is 4650 feet long including 1000 feet of cyclopean masonry, with gravity section, 210 feet high above the bed of Esopus Creek and 252 feet above the foundation, impounding with flashboards 130.5 billion gallons of available storage at elevation 591 west basin, 588 east basin, from 257 sq. mi. of drainage area at Olive Bridge in the Catskill Mountains west of Kingston.

Water was first obtained from Schoharie Reservoir in 1924. Its Gilboa Dam consists of an overflow cyclopean-masonry spillway 1324 feet long, 155 feet high above the bed of Schoharie Creek, 187 feet above the foundation, and an earth section with concrete core wall about 1000 feet long, impounding 19.6 billion gallons of available storage at elevation 1130 from 314 sq. mi. of drainage area at Gilboa. The water is diverted into Esopus Creek, a tributary of the Ashokan Reservoir, via the Shandaken Tunnel of horseshoe section 11 ft. - 6 in. x 10 ft - 3 in. 18.1 miles long, with a capacity of 650 mgd under full head.

The Catskill Aqueduct is about 92 miles long from Ashokan Reservoir to the Hill View Distributing Reservoir in Yonkers, elevation 295. It is for the most part a cut-and-cover conduit at grade, 17 ft. x 17 ft. - 6 in., horseshoe section, with a number of steel pipe siphons, and grade and pressure tunnels. A notable deep-rock tunnel siphon 14 ft. diameter, 1114 ft below sea level, crosses under the Hudson River above West Point. The aqueduct has a capacity in excess of 600 mgd.

Kensico Reservoir was constructed primarily as an equalizing basin on the Catskill Aqueduct but has a drainage area of 22 sq. mi. which provides an additional safe yield of 10 mgd. It also provides storage of water near the City as a safety factor against a breakdown of the Catskill Aqueduct. It is therefore maintained as full as the draft to the City and other factors permit. The Kensico Dam is of cyclopean masonry, with gravity section, 168 feet high above the bed of the Bronx River and 307 feet above the foundations, impounding, with permanent flashboards, 30.6 billion gallons of available storage at elevation 357 (from 22 sq. mi. of the Bronx River and Byram River drainage areas just north of White Plains). Incidentally, in constructing the Kensico Reservoir, the City diverted the flow from about 9 sq. mi. tributary to the Byram River. The payment of riparian damages was satisfactorily arranged and Connecticut did not make an issue of the interstate diversion to the point of taking the matter to the United States Supreme Court.

The water is distributed from Hill View Reservoir via two deep-rock tunnels which form a 38-mile loop, City Tunnel No. 1 with diameter decreasing

from 15 feet to 11 feet dipping to 704 feet below sea level under the Boroughs of the Bronx and Manhattan to Brooklyn, put into service in 1917, and City Tunnel No. 2 with diameter decreasing from 17 feet to 15 feet dipping to 553 feet below sea level under the Bronx, Queens and Brooklyn, put into service in 1936. From Brooklyn, two submarine pipes, 36 in. and 42 in. flexible-joint cast-iron, cross the Narrows to the Silver Lake Terminal Reservoir on Staten Island, elevation 228, supplying the Borough of Richmond. This supply can be advantageously supplemented locally in the Borough by wells which add 5 mgd of safe yield.

More than 30 years ago, before the Catskill supply was fully developed, the Board realized the necessity for immediate studies for an additional supply. Under the direction of the Chief Engineer, J. Waldo Smith, all possible sources within 200 miles were studied, resulting in a report by Department Engineer Walter E. Spear, dated November 9, 1923, as follows:

> "The Delaware River and its tributaries above Port Jervis, together with adjacent streams of the Hudson River basin, all on the westerly and southerly slopes and foothills of the Catskill Mountains, are nearer to the City than any other source of equal capacity and are sufficiently high for gravity delivery to the City. Compared with the supply just considered from the streams wholly within the Hudson River basin, it will be shown that a supply from these sources would be cheaper, softer and in the end much larger, so that, aside from the difficulties and delays that may be encountered in acquiring interstate waters, these Delaware River sources afford the best opportunity for developing a large and satisfactory supply of water for New York City."

Finally, the Board submitted its plan for the Delaware supply to be developed in three stages, for a total of 600 mgd (200 less than the 800 mgd now proposed). After five months' consideration, it was approved by the Board of Estimate in January, 1928, and submitted for approval to the State Water Power and Control Commission. This approval was given May 25, 1929, but not until after the State of New Jersey, on May 13, started action in the United States Supreme Court to prevent New York from diverting any water from the Delaware.

The Special Master in this first Delaware case, Charles N. Burch, Esq., was appointed January 27, 1930, and submitted his report February 2, 1931. The opinion of the Court was delivered by Mr. Justice Holmes on May 4, 1931, and the decree, which followed shortly afterward, authorized the diversion of the interstate water, but New York's allotment was reduced from the 600 mgd applied for to 440 mgd. However the decree provided that any of the parties involved could re-open the case and apply for a modification, and it is that provision which enabled New York to file its 1952 petition, requesting authorization of an additional 360, making a total of 800 mgd. In delivering the opinion of the Court, May 4, 1931, Mr. Justice Holmes stated:

> "We are met at the outset by the question what rule is to be applied. It is established that a more liberal answer may be given than in a controversy between neighbors members of a single State. Connecticut v. Massachusetts, February 24, 1931. Different considerations come in when we are dealing with independent sovereigns having to regard the welfare of the whole population and when the alternative to settlement is war. In a less degree, perhaps, the same is true of the quasi-sovereignties bound together in the Union. A river is more than an amenity, it is a treasure. It offers a necessity of life that must be rationed among those who have

power over it. New York has the physical power to cut off all the water within its jurisdiction. But clearly the exercise of such a power to the destruction of the interest of lower States could not be tolerated. And on the other hand equally little could New Jersey be permitted to require New York to give up its power altogether in order that the river might come down to it undiminished. Both States have real and substantial interests in the River that must be reconciled as best they may be. The different traditions and practices in different parts of the country may lead to varying results but the effort always is to secure an equitable apportionment without quibbling over formulas."

By the terms of that decree of 1931, New York was allowed to proceed with the construction of the first and second stages of its Delaware Supply and to divert the equivalent of 440 mgd, but delays, caused principally by the Court Case and by World War II, are responsible for the fact that the construction of the second stage, comprising the development on the East Branch of the Delaware River, has not yet been completed.

The Delaware Supply – The entire supply from New York's Delaware tributaries is diverted into Rondout Reservoir, the last to be developed in the Hudson drainage basin. This reservoir impounds 48.7 billion gallons of available storage at elevation 840 from 95 sq. mi. drainage area in the Catskills at Lackawack, and has a safe yield from its own watershed of 120 mgd. The Merriman Dam, which forms this reservoir, is a rolled-fill earth embankment 2400 feet long and 195 feet high above the bed of Rondout Creek and its concrete core wall, the deep portion of which was constructed with rectangular sectioned caissons, extends to a depth of 180 feet below the bed.

The Delaware Aqueduct, first made available in 1944, is a deep-rock tunnel for its entire length from Merriman Dam to Hill View Distributing Reservoir, 85 miles, over six times as long as the Simplon Tunnel under the Alps. Its maximum depth below the surface is about 2500 feet. Its deepest construction shaft was sunk 1551 feet, which is greater than the height of the Empire State Building. It passes under the Hudson River at 600 feet below sea level. It is connected by uptake and downtake shafts not only to Kensico Reservoir but also to another equalizing basin, the West Branch Reservoir, elevation 503, where 43 sq. mi. of the Crotan watershed can be intercepted at this high elevation.

The Delaware Aqueduct is 13 ft. - 6 in. diameter for the first 44.2 miles to West Branch Reservoir, 15 ft. for the next 27.2 miles to Kensico Reservoir and 19 ft. - 6 in. for the remaining 13.6 miles to Hill View Reservoir. The capacity of this aqueduct across the Hudson River Valley to West Branch Reservoir is sufficient to accommodate, in addition to the yield of the Rondout Reservoir drainage area, 800 mgd potential diversion from tributaries of the Delaware River. From West Branch Reservoir to Hill View Reservoir it has a higher capacity. The operation of the system is made flexible by interconnections, at Kensico and Hill View Reservoirs, with the Catskill Supply. It also has connections from the lower Croton System at two pumping plants, and also as above noted at West Branch Reservoir without pumping.

The Neversink Reservoir, the first to be developed in the Delaware River watershed, has a safe yield of 115 mgd. The first interstate diversion from this reservoir was started January 1, 1954. Its Neversink Dam is a rolled-fill earth embankment 2820 feet long and 195 feet high above the bed of the Neversink River and its concrete-caisson core wall extends to a depth of 150 feet below the bed. It impounds 34.7 billion gallons of available storage at elevation 1440 from 93 sq. mi. drainage area at Neversink. The Neversink

Tunnel is 10 ft. in diameter, 5.5 miles long to the upper end of Rondout Reservoir, where the discharge is through a 36,000 H.P. water turbine with 31,250 KVA generator.

The Pepacton Reservoir, the second to be developed in the Delaware River watershed, will have a safe yield of 375 mgd. Its Downsville Dam is a rolled-fill earth embankment 2450 feet long and 204 feet high above the bed of the East Branch of the Delaware River and its concrete core wall extends to a depth of 100 feet below the bed. It will impound 143.5 billion gallons of available storage at elevation 1280 from 372 sq. mi. of drainage area at Downsville. The East Delaware Tunnel is 11 ft. - 4 in. diameter, 25 miles long to the upper end of Rondout Reservoir where the discharge will be through a 25,000 H.P. water turbine with 22,500 KVA generator. The works are nearing completion and it is expected that water from this source should be made available sometime in 1955.

There is a difference in flow line elevation of 600 ft. between Neversink Reservoir and Rondout Reservoir, and 440 ft. between Pepacton Reservoir and Rondout Reservoir. Hence it was necessary to provide for the dissipation of energy at the two tunnel outlets. To accomplish this in the case of the Neversink, a power plant was constructed, and is being operated, by the Central Hudson Gas and Electric Corporation under a 50-year agreement which will compensate the Power Company for certain diversion damages. In the case of the Pepacton Reservoir a power plant is being constructed, and will be operated, by the Rockland Light and Power Company under a similar agreement.

Figure 2, above referred to, shows in plan, the drainage areas and aqueducts of all these three water supply systems: The Croton System, East of the Hudson River, with its many reservoirs and its two aqueducts. The Catskill System, with its two reservoirs and the Catskill Aqueduct crossing the Hudson River above West Point. The Delaware System, with its three reservoirs, and a fourth contemplated, and the Delaware Aqueduct crossing the Hudson above Newburgh.

Figure 3 shows the relation between these three systems in diagrammatic form and shows the actual average distribution of yield, aqueduct flow and consumption for the calendar year 1953.

New York under present conditions counts on some yield from wells in Long Island and those of Private Companies, and some additional yield would be available in an emergency from the City's temporary pumping plant on the Hudson River, which has a few more years of life before its abandonment is required by the State Water Power and Control Commission.

The average rate of consumption last year, 1953, was 1139 mgd with every expectation of reaching at least 1160 mgd in 1954. A glance at the above table shows that if it were not for the fact that the Board has nearly completed the Pepacton Reservoir, or second stage of the Delaware Supply, New York would have no adequate reserve. As it is, the City is close to facing the same sort of a critical situation which it faced in 1949 and 1950, when drastic conservation measures had to be resorted to.

This was not a mere cutting off of unnecessary use and waste. In fact New York is not an extravagant user of water, considering its size. Its daily per capita consumption was 136 in 1952 and the same in 1953. This per capita rate is the smallest of the nine largest cities in the United States. Of the other eight, Chicago's, 229 gals. per capita in 1952, was the largest, and the City of Boston's, 141, the smallest, next to New York's.

The past record of the per capita consumption of New York City and of these other large cities is shown on Figure 4. New York's upward trend has been at the rate of about 0.7 g.p.c.d. per year and the ups and downs are within a range of as much as 20 g.p.c.d., or plus or minus 10 g.p.c.d. In projecting this into the future for exhibit purposes in the interstate diversion case, the City was not unduly conservative. It was assumed that the trend of consumption increase will decrease after 1980 to the same general trend as indicated by the average of all the nine largest cities, namely, 0.5 g.p.c.d. per year, actually a much smaller rate of increase than was conceded as justifiable by opposing testimony in the Supreme Court Case.

Estimated Population and Consumption

	Population of New York City	Approx. Gals. per Capita per day		Consumption by New York City M.G.D.	Supplied to Outside Communities M.G.D.	Total Consumption M.G.D.
		Average of ups and downs	Quantity that must be provided			
1950 (Actual)	7,892,000	121		950	29	979
1953 (Actual)	8,050,000 ±	136		1094	45	1139
1960	8,366,000	147	157	1313	50	1363
1970	8,785,000	153	163	1432	80	1512
1980	9,210,000	159	169	1556	105	1661
1990	9,598,000	164	174	1670	125	1795
2000	9,955,000	169	179	1782	145	1927

The following tabulation summarizes the yield from New York City's water supply sources above described:

	Approximate Average Million Gallons Daily		
	Actually used by City and dependent outside communities in 1952 and 1953. These were not critically dry years, hence yields were much increased and a relatively greater quantity was drawn from the more desirable sources.		Safe Yield that can be depended on in the future in a critical drought:
Sources of New York City's Supply	1952	1953	
From the Old Croton Supply:			
by gravity	160 mgd	186 mgd	175 mgd
by pumping	86 mgd	124 mgd	155 mgd
From Kensico Watershed	34 mgd	34 mgd	10 mgd
From Wells in Richmond	1 mgd	2 mgd	5 mgd
From Municipal Wells in Long Island	3 mgd	14 mgd	0 mgd
From Wells of Private Companies	40 mgd	41 mgd	0 mgd
From the Catskill Supply	601 mgd	570 mgd	555 mgd
From the Delaware Aqueduct Supply:			
Rondout Reservoir	196 mgd	168 mgd	120 mgd
Interstate Diversions			
Neversink Reservoir		(only 440 mgd authorized by 1931 Decree)	115 mgd
Pepacton Reservoir, nearing completion			375 mgd
Cannonsville Reservoir, proposed			310 mgd
	1121 mgd	1139 mgd	1820 mgd

The following is a brief summary of the progress of the interstate diversion case before the United States Supreme Court.

The City's petition to the Court to reopen the case was filed April 1, 1952, and was joined in by the State of New York. New Jersey's answer was filed on June 2, and Pennsylvania's on May 16, of that year. The City of Philadelphia moved to intervene but its Motion was denied April 6, 1953. Delaware's motion to intervene was granted April 12, 1954.

Before the City could file the above application to the Court for an additional supply, it had to obtain approval by the New York City Board of Estimate and by the New York State Water Power and Control Commission, of its specific plan for the proposed reservoir on the West Branch of the Delaware at Cannonsville.

At that time the pros and cons of the alternative plan of pumping and filtering Hudson River water were thoroughly aired at public hearings, and the stamp of approval given to the City's plan which included the construction of a reservoir at Cannonsville with a flow line at Elevation 1150 and a net available storage capacity of about 91.2 billion gallons, the Board's engineers having conservatively estimated that such a reservoir would be needed to obtain the necessary additional yield for the City and to make such compensation releases to the river as might be required.

In the original Decree of 1931 such compensation was obtained by requiring in effect a release from each reservoir of 0.66 cfs per square mile of its tributary area whenever the flow, either crossing the State line at Port Jervis, New York, or entering tidewater at Trenton, New Jersey, dropped below 0.5 cfs per square mile. In the City's petition of April 1, 1952, compensation was to be accomplished by a release formula of the type which had been proposed several years earlier by the Interstate Commission on the Delaware River Basin, known as Incodel, or specifically: that the rate of release at each diversion point be 50 per cent of the mean annual runoff whenever the recorded rate of flow falls below that which is exceeded 90 per cent of the time; 25 per cent whenever the rate of flow is between that which is exceeded 90 per cent and that which is exceeded 76 per cent of the time; and no release when the rate of flow is greater than that.

The Court appointed Kurt F. Pantzer, Esq. of Indianapolis, as Special Master on June 9, 1952, to take evidence and report his recommendations. A comprehensive view of the watershed was first had, a number of informal conferences were held, some between counsel for all parties, some between both counsel and engineers and last, but by no means least, many between the engineering representatives of two or more of the parties.

As a result, the representatives of New York and New Jersey on February 17. 1953, agreed to recommend a substitute formula for the making of compensating releases to the River which included a very practical solution to the problem. The City forthwith filed an amended petition on March 12, 1953, incorporating the new formula, to take effect upon the completion of the East Branch Reservoir new under construction.

From a practical standpoint, operation under this new formula will be greatly simplified due to the reduction of the number of control points to only one, namely, the U.S.G.S. gaging station located at Montague, New Jersey, about 8 miles below the New York State line. Under this new Montague formula so-called, the City will, after completing the proposed reservoir at Cannonsville, maintain a minimum basic rate of flow in the Delaware River at Montague substantially equal to 1750 cfs or approximately 0.503 csm. In the short intervening period of 10 or 12 years until the Cannonsville Reservoir is

put in operation, this minimum flow will be substantially equal to 1525 cfs or approximately 0.438 csm.

Furthermore, under this formula, so long as New York's consumption anticipated for any year does not exceed that which would compel it to use in a critical drought existing sources that require pumping, as much of what would otherwise be spillway waste, as New York can safely permit to be released in advance, will be so released as excess commencing June 15, mostly during July, August, September and October, when most needed in the lower river rather than held back to be wasted to no avail the following spring. The formula sets limits on the determination of such excess as follows: (1) 70 billion gallons in any year, boosting the basic rate to not over 2650 cfs, (2) City's anticipation of its consumption to be not over 20 mgd more than any previous yearly average, (3) safe yield of existing sources in a critical drought, with no pumping required, to be not less than 1355 mgd before Cannonsville and not less than 1665 mgd after Cannonsville (plus any net increase from new developments before 1993).

What this means can be briefly summarized as follows: After Cannonsville Reservoir is completed this will add to the dry-months flow in the river, 900 cfs of 0.259 csm until after the total consumption from all New York's sources has come within 20 mgd of reaching a limiting annual average of 1434 mgd, and will continue adding decreasing amounts to the flow until the consumption is increased by another 231 mgd. After the upper limit of 1665 mgd is reached, the above noted basic rate of 1750 cfs in the river will be continued indefinitely. In the short intervening period before Cannonsville is put in operation, a decreasing amount of such excess will be released until after the consumption comes within 20 mgd of the limiting figure of 1355 mgd, after which the above noted basic rate of 1525 cfs will be continued until Cannonsville is built.

This new Montague formula was discussed at length between New York's, New Jersey's and Pennsylvania's lawyers and engineers and a tentative agreement reached on June 22, 1953, that "it is now possible for all parties to make certain recommendations to the Special Master. * * * * * * In consideration of the increased capacity of the lower Basin resulting from the modified release formula thus offered by New York, New Jersey and Pennsylvania will not oppose the proposed diversions by New York. * * * * * * In flood times, there is more than enough water in the Delaware for everyone. In seasons of abnormally low flow, the releases which New York has agreed to make will be a great boon to the Lower Delaware. In the opinion of the engineers for Pennsylvania and New Jersey the additional diversion by New York City under its enlarged plan of development will, if conditions do not change, have no adverse effect on the interests of Pennsylvania and New Jersey, but on the contrary will further such interests by increasing the quantity of water available to those States."

In spite of this agreement Pennsylvania's consent to join in the recommendation was qualified principally on account of issues that were raised between New Jersey and Pennsylvania. New Jersey wished to establish its right to continue certain diversions outside the watershed by its Delaware and Raritan Canal, and Pennsylvania wished to establish, by appropriate New Jersey legislation, the fact that, when and if it desired to make a water supply diversion of its own, it would have the right to build a dam across the Delaware River between the two States. The necessary legislation was passed on December 24, by Chapter 443 of the New Jersey Laws of 1953.

Since the case is still before the Court at this printing, its merits cannot well be discussed in further detail at this time. However, some idea of the

ramifications of the case may be had from a brief outline of the testimony which New York submitted.

New York commenced the circulation of testimony among all the parties to the case by distributing, on January 8, 1953: (1) testimony by the Water Supply Board's President, Irving V. A. Huie, setting forth the factual history of the development of its proposed plan and the reasons why its request for additional interstate water is an urgent one, and (2) testimony and exhibits by the Board's Deputy Chief Engineer in charge of Research, Henry Z. Pratt, Jr., explaining the details of all the basic data on river flows. Much time had been spent in preparing exhibits in the form of daily before-and-after hydrographs covering the entire period of U.S.G.S. records commencing in 1914. In a very real sense, New York's entire case rested on these hydrographs, the accuracy of which was not questioned. On January 21, New York circulated testimony by one of our Diversion Engineers, Vincent G. Terenzio, explaining in a great detail the results of studies over a long period of time to determine the seasonal variation of salinity in the tidal portions of the river and estuary and the effect of river flow, tides, etc., on the location of the so-called salt front. On February 3, New York circulated testimony by the writer, confirming New York's urgent need, analyzing the physical characteristics and yields of the entire watershed with relation to New York's proposal, and pin-pointing the benefits accruing to the lower river and bay. His exhibits included a report by the Woods Hole Oceanographic Institution on the distribution of salinity in the estuary of the Delaware River.

Briefly stated, the total drainage area of the Delaware River above tidewater at Trenton amounts to 6780 square miles. Of that total, there are 2380 square miles in New York, 3460 square miles in Pennsylvania, and 940 square miles in New Jersey. The Cannonsville Reservoir will develop a drainage area of 450 square miles, the Neversink reservoir has a drainage area of 93 square miles, and the East Branch reservoir 372 square miles. The three reservoirs together will develop approximately 39% of the drainage area of the Delaware River located in the State of New York.

The average long-term runoff of the watershed above Trenton amounts to about 11,810 cubic feet per second (c.f.s.) or 7640 m.g.d. Of that total runoff, about 4295 c.f.s. or 2780 m.g.d. is derived from the New York watershed; 5925 c.f.s. or 3830 m.g.d. from the Pennsylvania watershed; and 1590 c.f.s. or 1930 m.g.d. from the New Jersey watershed. (The total mean annual runoff from New York's three developments is 1689 c.f.s. or 1091 m.g.d.) Of this total runoff only about 29% is to be diverted for municipal water supply by the City. Considered in terms of the entire watershed above Trenton New York proposes to use for its municipal water supply only 10.4% of the runoff.

In respect to storage, the two developments on the Neversink and East Branch provide 178 billion gallons of storage. The Cannonsville development will provide an additional storage of 91 billion gallons, bringing the total storage of the three developments to 269 billion gallons. Under the Montague formula the City must devote at all times in the future a minimum of 85 billion gallons, or 32% of its total storage, to river regulation.

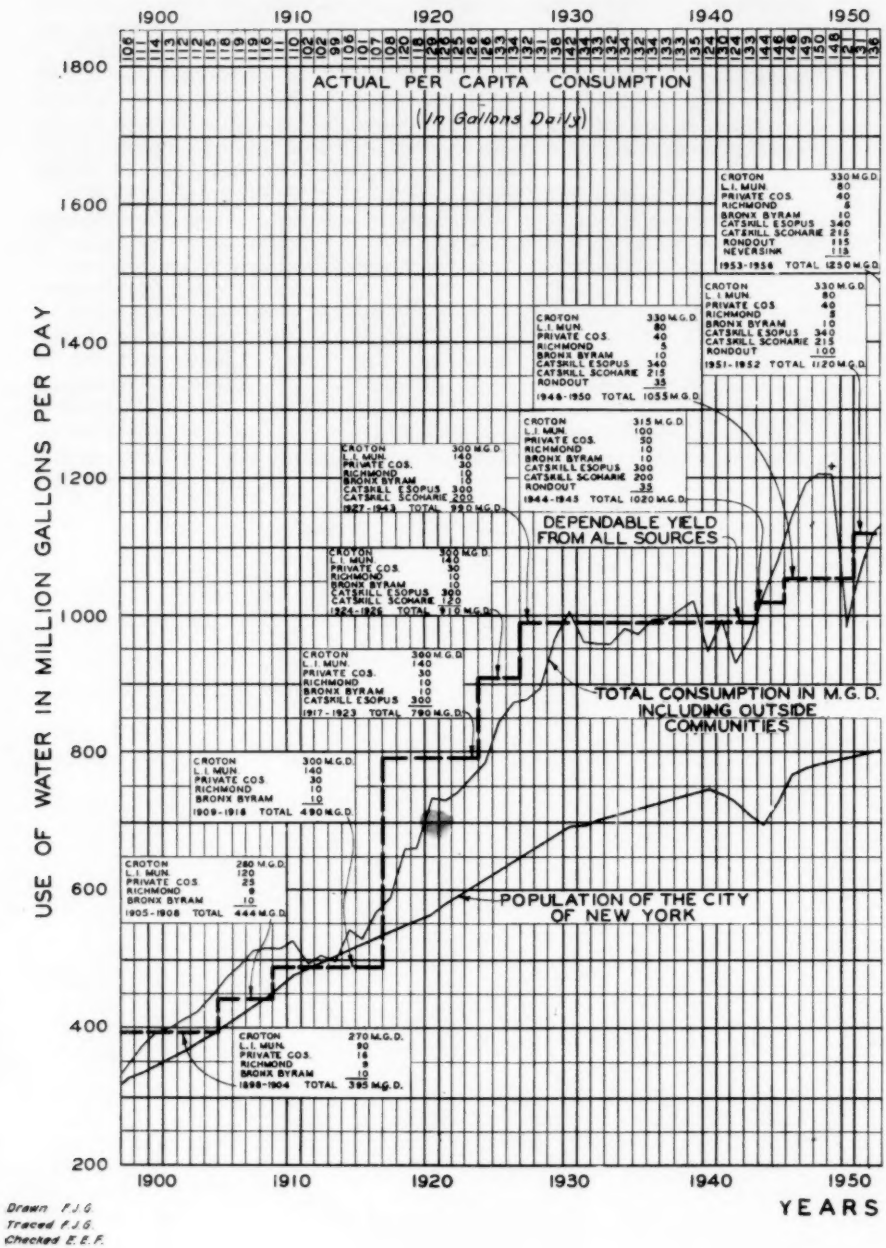
As already stated, New York's amended petition incorporating the Montague Formula was then filed March 12, 1953. On June 2, New York circulated: (1) supplemental testimony by all four of the above witnesses, modifying their previous testimony to conform to this new formula, explaining the additional benefits to the lower river resulting from the substitution of this formula; and also (2) testimony by Consulting Engineer Frank A. Marston, describing the results obtained in the sewage treatment plant for the City of Port Jervis

which was required by the Decree of 1931 to be constructed as a precedent to any diversion by New York City.

Following the circulation by New Jersey, on June 30, 1953, of its testimony, New York circulated, on September 21, 1953, supplemental and rebuttal testimony including that of Consulting Biological Engineer Joseph B. Glancy, discussing the oyster industry in Delaware Bay and the effect of New York's proposed diversion, and that of Dr. Bostwick H. Ketchum, Marine Microbiologist at the Woods Hole Oceanographic Institution.

In the interest of clarifying the issues, a trial memorandum was issued December 22, 1953, by the City and State of New York which presents a complete history of the case and a summary of New York's testimony to that date. (It was followed by the supplemental memorandum of April 17, 1954, which completed New York's case.)

Following the passage by the New Jersey Legislature of the permissive legislation above referred to, Pennsylvania, on January 5, 1954, circulated its testimony. In lieu of any cross-examination, rebuttal testimony was circulated by New York City on February 11, by New Jersey on March 17, and by Pennsylvania on March 19. Delaware circulated its testimony on March 24. Pennsylvania, on April 7, circulated surrebuttal testimony by one of its witnesses. The final hearing for the record, before the Special Master was held in Philadelphia, April 15.



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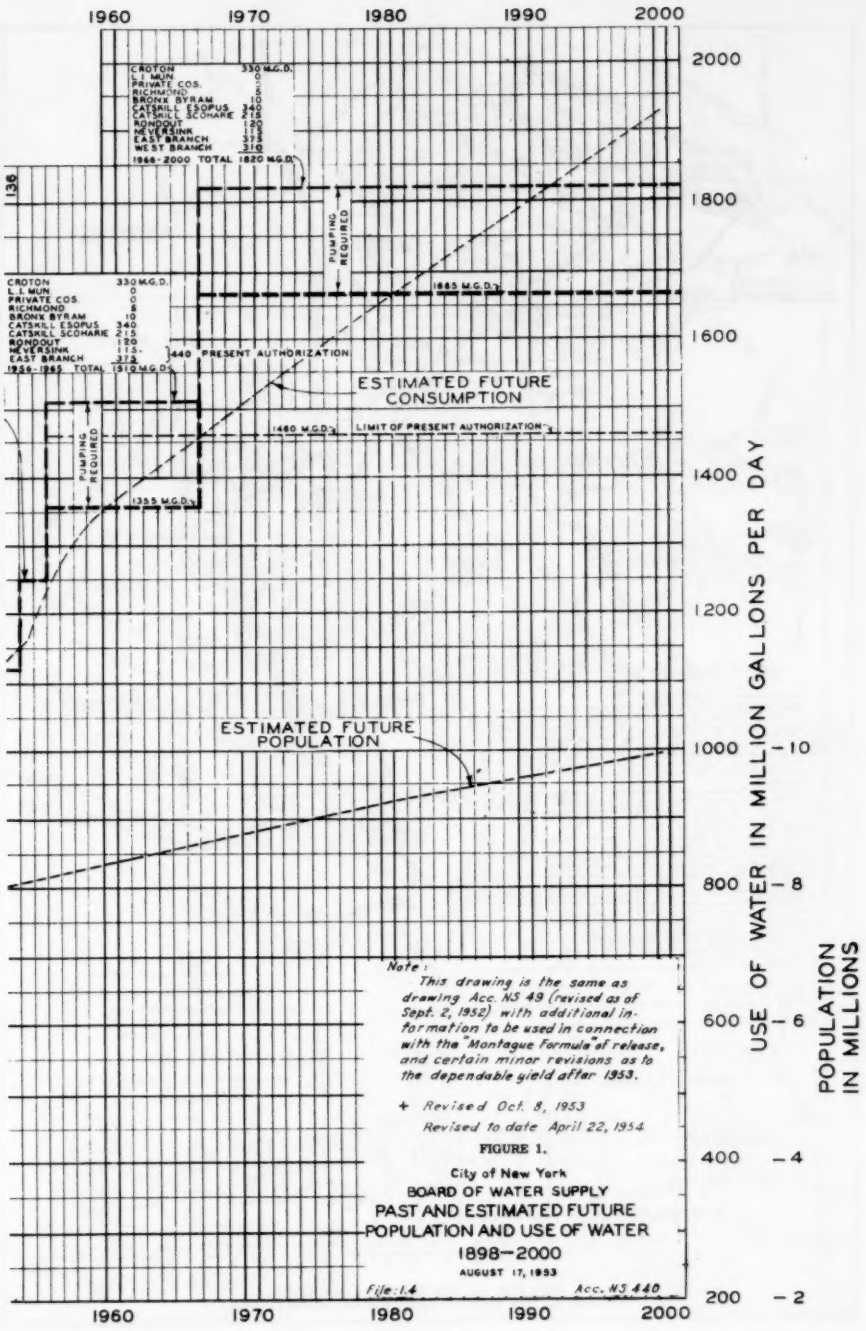


Note:

This drawing is the same as drawing Acc. NS 49 (revised as of Sept. 2, 1952) with additional information to be used in connection with the "Montague Formula" of release, and certain minor revisions as to the dependable yield after 1953.

+ Revised Oct. 8, 1953

Revised to date April 22, 1954

FIGURE 1.

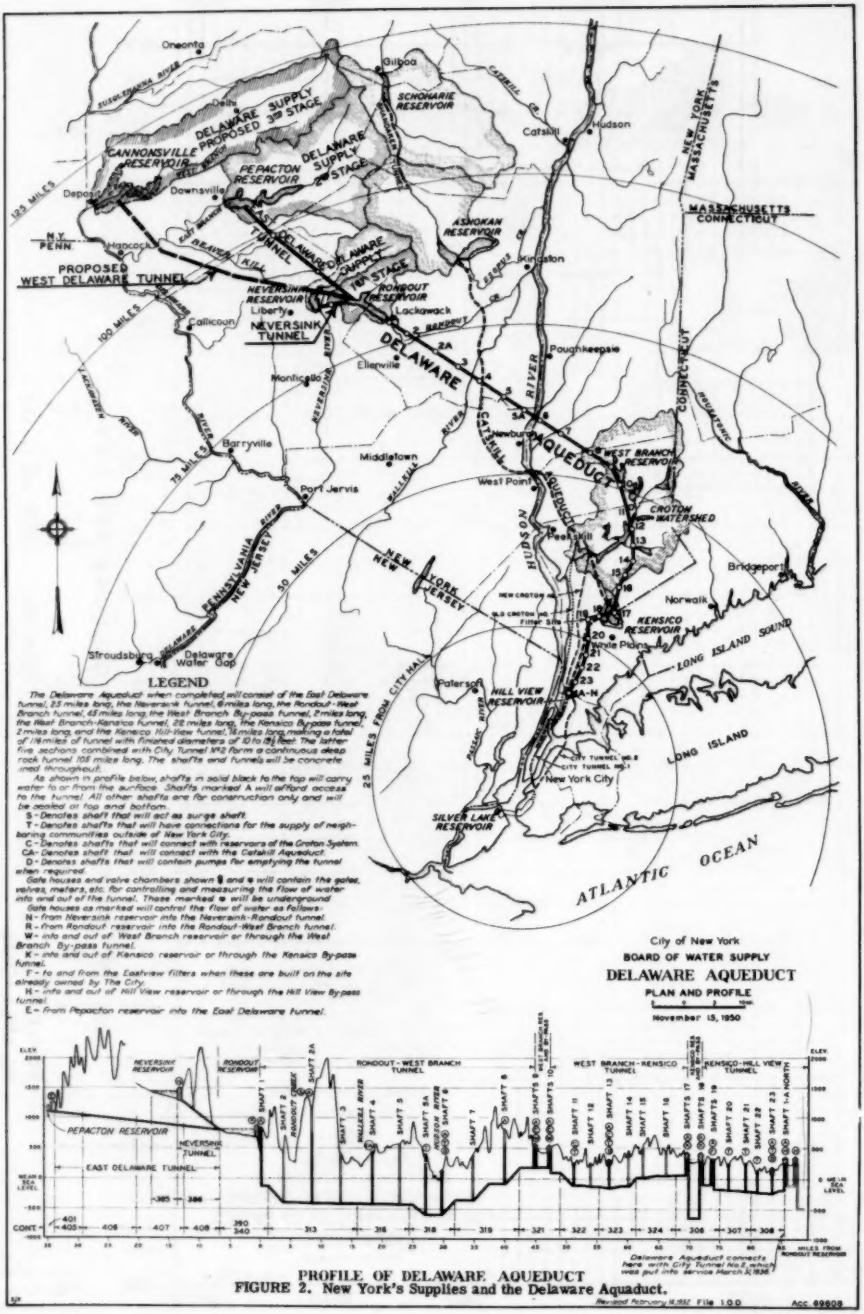
City of New York

BOARD OF WATER SUPPLY

PAST AND ESTIMATED FUTURE POPULATION AND USE OF WATER 1898—2000

AUGUST 17, 1953

File: L4 *Acc. NS 440*



LEGEND

The Delaware Aqueduct when completed will consist of the East Delaware tunnel, 25 miles long, the Neversink tunnel, 6 miles long, the Rondout-West Branch tunnel, 45 miles long, the West Branch By-pass tunnel, 2 miles long, the West Branch-Kensico tunnel, 22 miles long, the Kensico By-pass tunnel, 2 miles long, and the Kensico Hill-View tunnel, 16 miles long, making a total of 118 miles of tunnel with finished diameters of 10 to 25 feet. The latter five sections combined with City Tunnel №2 form a continuous deep rock tunnel 105 miles long. The shafts and tunnels will be concrete lined throughout.

As shown in profile below, shafts in solid black to the top will carry water to or from the surface. Shafts marked A will afford access to the tunnel. All other shafts are for construction only and will be sealed at top and bottom.

S - Denotes shaft that will act as surge shaft.

T - Denotes shafts that will have connections for the supply of neighboring communities outside of New York City.

C - Denotes shafts that will connect with reservoirs of the Croton System.

Ca - Denotes shaft that will connect with the Catskill Aqueduct.

D - Denotes shafts that will contain pumps for emptying the tunnel when required.

Gate houses and valve chambers shown ■ and ● will contain the gates, valves, meters, etc. for controlling and measuring the flow of water into and out of the tunnel. Those marked ● will be underground.

Gate houses as marked will control the flow of water as follows:

N - from Neversink reservoir into the Neversink-Rondout tunnel.

R - from Rondout reservoir into the Rondout-West Branch tunnel.

W - into and out of West Branch reservoir or through the West Branch By-pass tunnel.

K - into and out of Kensico reservoir or through the Kensico By-pass tunnel.

F - to and from the Eastview filters when these are built on the site already owned by The City.

H - into and out of Hill View reservoir or through the Hill View By-pass tunnel.

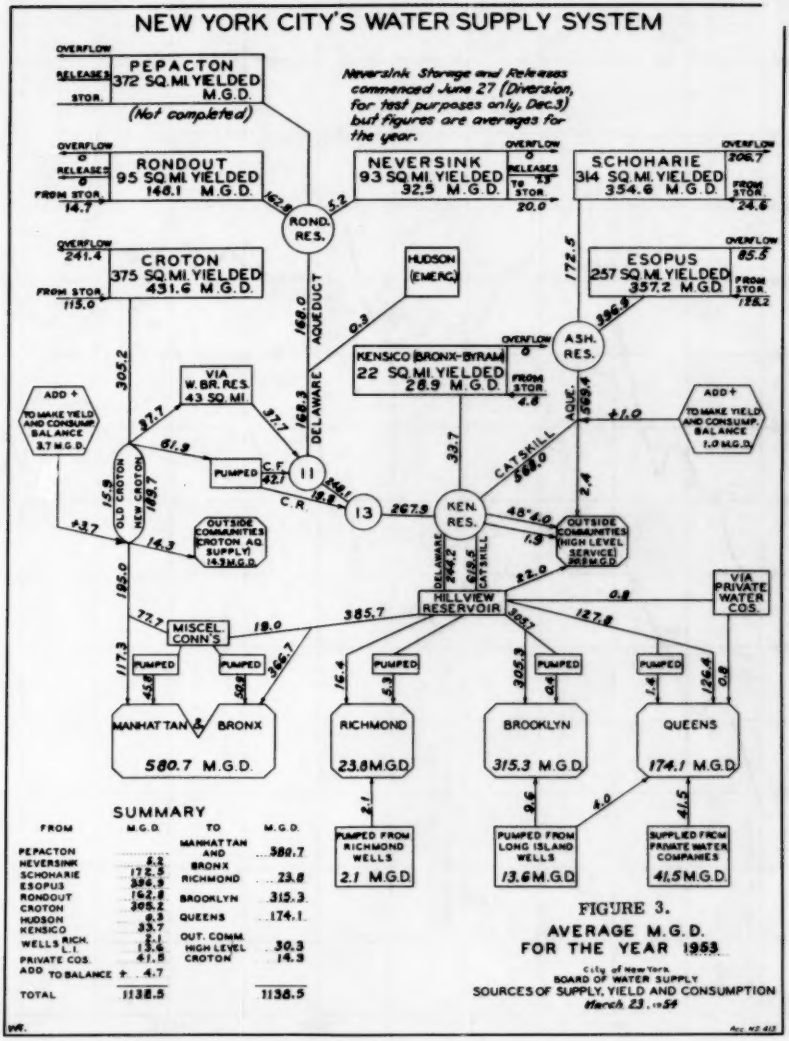
E - From Pepacton reservoir into the East Delaware tunnel.

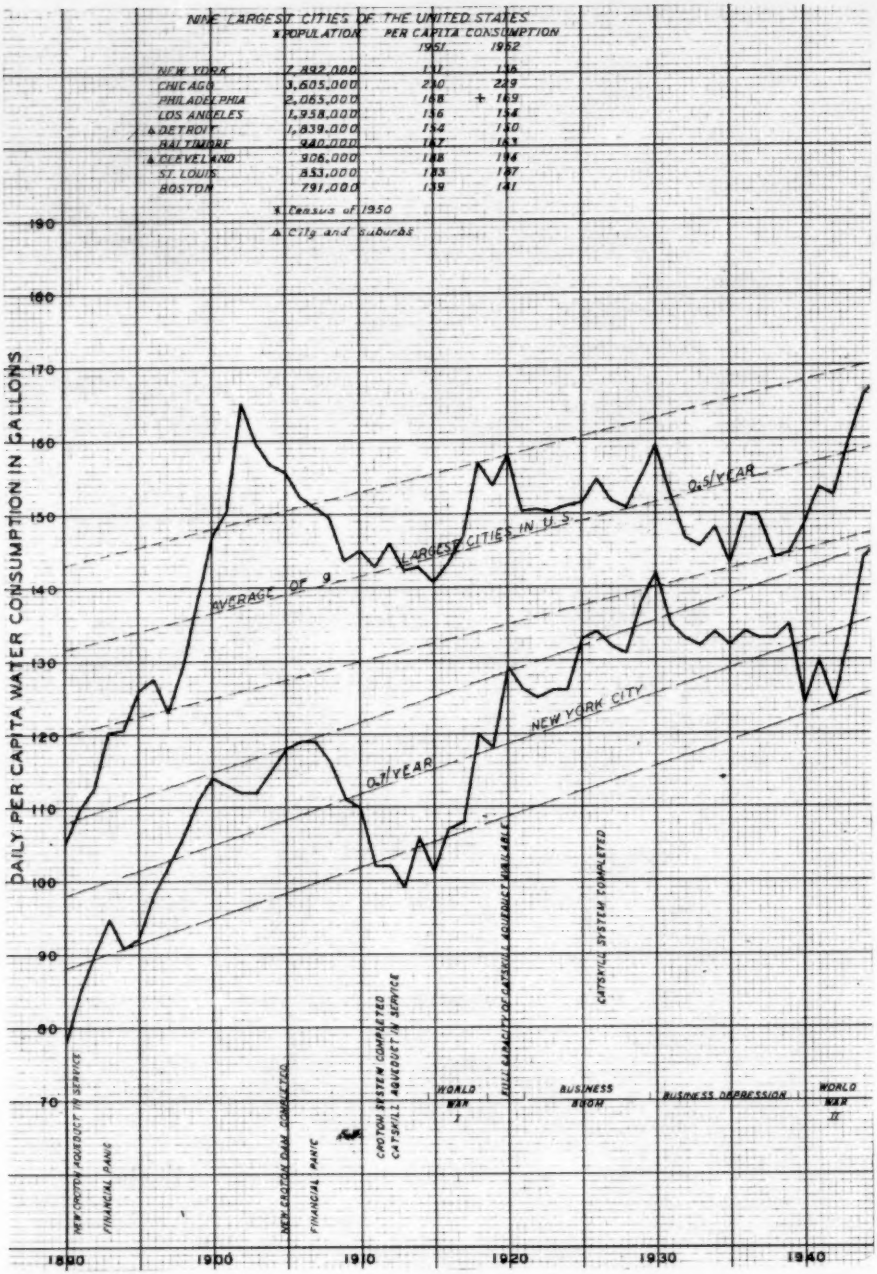
City of New York
BOARD OF WATER SUPPLY
DELAWARE AQUEDUCT
PLAN AND PROFILE
November 15, 1950

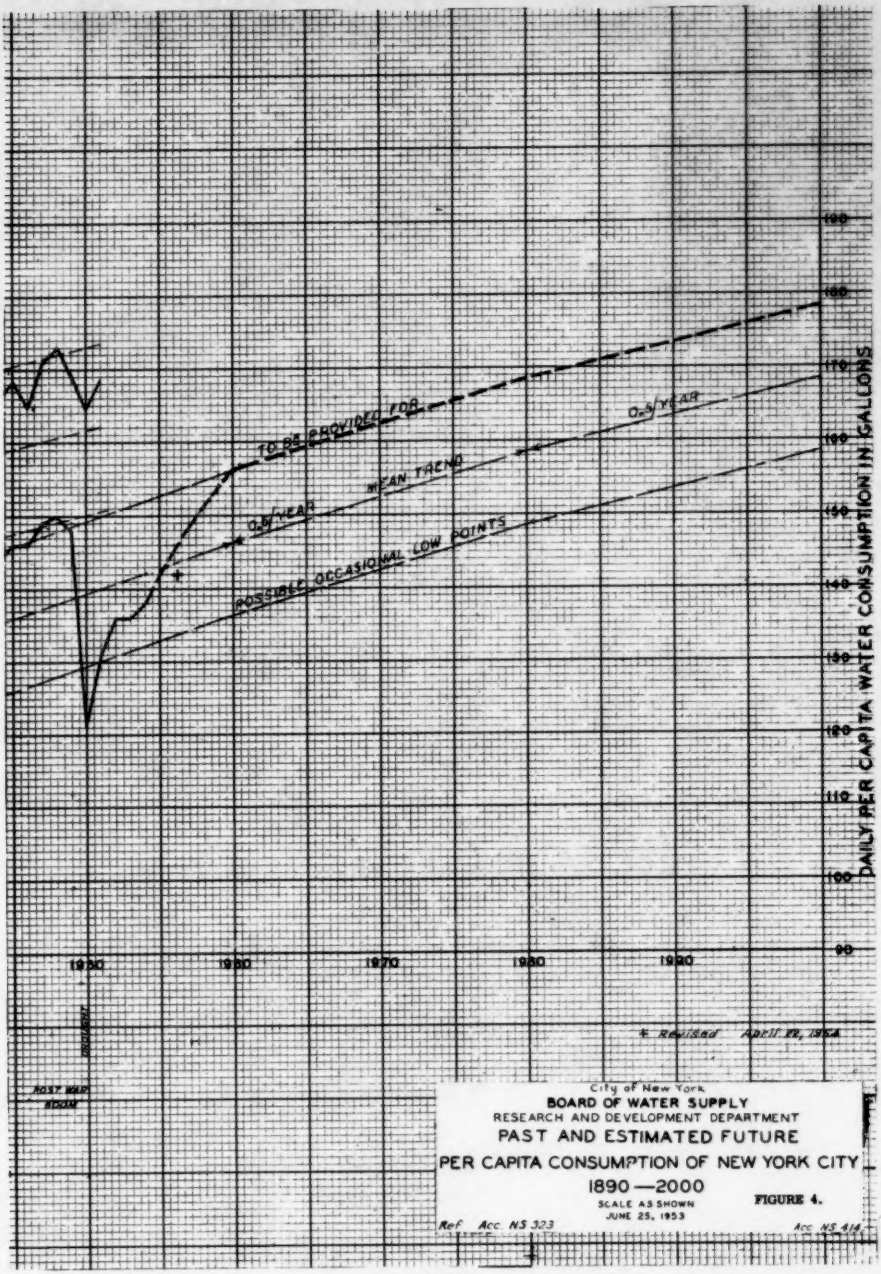
PROFILE OF DELAWARE AQUEDUCT

FIGURE 2. New York's Supplies and the Delaware Aquaduct.

Revised February 14, 1952 File 1.00 Acc. 69909


NEW YORK CITY'S WATER SUPPLY SYSTEM
PEPACTON
372 SQ.MI. YIELDED
M.G.D.
(Not completed)
RONDOUT
95 SQ.MI. YIELDED
148.1 M.G.D.
NEVERSINK
93 SQ.MI. YIELDED
32.5 M.G.D.
SCHOHARIE
314 SQ.MI. YIELDED
354.6 M.G.D.
CROTON
375 SQ.MI. YIELDED
431.6 M.G.D.
ESOPUS
257 SQ.MI. YIELDED
357.2 M.G.D.
KENSICO BRONX-BYRAM
22 SQ.MI. YIELDED
28.9 M.G.D.
Neversink Storage and Releases commenced June 27 (Diversion, for test purposes only, Dec.3) but figures are averages for the year.
ROND. RES.
ASH. RES.
KEN. RES.
HILLVIEW RESERVOIR
HUDSON (EMERG.)
VIA W. BR. RES. 43 SQ. MI.
ADD + TO MAKE YIELD AND CONSUMP. BALANCE 3.7 M.G.D.
ADD + TO MAKE YIELD AND CONSUMP. BALANCE 1.0 M.G.D.
OUTSIDE COMMUNITIES CROTON AQ. SUPPLY 143 M.G.D.
OUTSIDE COMMUNITIES (HIGH LEVEL SERVICE) 28.8 M.G.D.
VIA PRIVATE WATER COS.
MISCEL CONN'S
PUMPED
C.F. 42.7
C.R. 19.8
MANHATTAN & BRONX
580.7 M.G.D.
RICHMOND
23.8 M.G.D.
BROOKLYN
315.3 M.G.D.
QUEENS
174.1 M.G.D.
PUMPED FROM RICHMOND WELLS
2.1 M.G.D.
PUMPED FROM LONG ISLAND WELLS
13.6 M.G.D.
SUPPLIED FROM PRIVATE WATER COMPANIES
41.5 M.G.D.
SUMMARY
FROM M.G.D.
PEPACTON
NEVERSINK 4.2
SCHOHARIE 172.5
ESOPUS 394.9
RONDOUT 162.8
CROTON 305.2
HUDSON 8.3
KENSICO 33.7
WELLS RICH. 2.1
L.I. 13.6
PRIVATE COS. 41.5
ADD TO BALANCE + 4.7
TOTAL 1138.5
TO M.G.D.
MANHATTAN AND BRONX 580.7
RICHMOND 23.8
BROOKLYN 315.3
QUEENS 174.1
OUT. COMM. HIGH LEVEL 30.3
CROTON 14.3
1138.5
FIGURE 3.
AVERAGE M.G.D.
FOR THE YEAR 1953
City of New York
BOARD OF WATER SUPPLY
SOURCES OF SUPPLY, YIELD AND CONSUMPTION
March 23, 1954


NINE LARGEST CITIES OF THE UNITED STATES
POPULATION
PER CAPITA CONSUMPTION
1951
1952
NEW YORK 7,892,000 131 136
CHICAGO 3,605,000 230 229
PHILADELPHIA 2,065,000 168 + 169
LOS ANGELES 1,958,000 136 134
& DETROIT 1,839,000 154 150
BALTIMORE 940,000 167 163
& CLEVELAND 906,000 188 196
ST. LOUIS 853,000 133 137
BOSTON 791,000 139 141
* Census of 1950
Δ City and suburbs
DAILY PER CAPITA WATER CONSUMPTION IN GALLONS
190
180
170
160
150
140
130
120
110
100
90
80
70
AVERAGE OF 9 LARGEST CITIES IN U.S.
0.5/YEAR
NEW YORK CITY
0.7/YEAR
NEW CROTON AQUEDUCT IN SERVICE
FINANCIAL PANIC
NEW CROTON DAM COMPLETED
FINANCIAL PANIC
CROTON SYSTEM COMPLETED
CATSKILL AQUEDUCT IN SERVICE
WORLD WAR I
FULL CAPACITY OF CATSKILL AQUEDUCT REACHED
BUSINESS BOOM
CATSKILL SYSTEM COMPLETED
BUSINESS DEPRESSION
WORLD WAR II
1890
1900
1910
1920
1930
1940


DAILY PER CAPITA WATER CONSUMPTION IN GALLONS
TO BE PROVIDED FOR
0.8/YEAR
MEAN TREND
0.5/YEAR
POSSIBLE OCCASIONAL LOW POINTS
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
* Revised April 28, 1954
City of New York
BOARD OF WATER SUPPLY
RESEARCH AND DEVELOPMENT DEPARTMENT
PAST AND ESTIMATED FUTURE
PER CAPITA CONSUMPTION OF NEW YORK CITY
1890 — 2000
SCALE AS SHOWN
JUNE 25, 1953
FIGURE 4.
Ref. Acc. NS 323
Acc. NS 414

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